Radio Frequency Energy and Impedance Feedback

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Purpose:

The object of this study was to show the potential use of tissue electrical impedance as a feedback parameter for the control of therapeutic Radio Frequency (R.F.) energy.

Radio Frequency energy is a form of electromagnetic energy with an usable frequency range between 200KHZ and 2MHZ. The low frequency limit is determined by the physiological stimulation of muscle, and the high frequency is limited by the physics of the delivery system.

Nikola Tesla first introduced R.F. energy to the scientific community in the late 1800's and received a patent in communications in May, 1900. The principle of R.F. energy was adopted by Bovie in the development of early electrosurgical units (E.S.U.). The early E.S.U. utilized R.F. energy for cutting and coagulation by delivering energy to the tissue through a variety of electrodes consisting of a large surface area return electrode and a small surface area electrode placed at the surgical site. The area of the return electrode is large enough to minimize the heat created by the R.F. energy density and conversely the area of the active electrode is minimized to focus the energy into a small area causing extreme heat (high current density).

Solid state E.S.U.'s were introduced in the sixties and offered a new degree of safety for the patient and surgeon in addition to the reduction in the size and weight of the units. Furthermore, Bi-Polar applications were investigated and advanced by Malis, Greenwood and others. Bi-Polar offers the advantage of containing the R.F. energy to the tissue between the tines of the Bi Polar forceps in contrast to the monopolar energy path.

A more modern application of R.F. energy is it's introvascular use for cardiac ablation, thermal balloon angioplasty (R.F. T.B.A.)[1] and recanalization. Dr. Jackman, et al,[2] have shown that an accessory pathway in the cardiac conduction system can be successfully ablated by applying R.F. energy between an electrode placed at the anulus of the left ventrical and a second electrode placed directly opposite it in the coronary sinus (Figure 1). During the application of energy, current and voltage are recorded and are used to derive impedance.

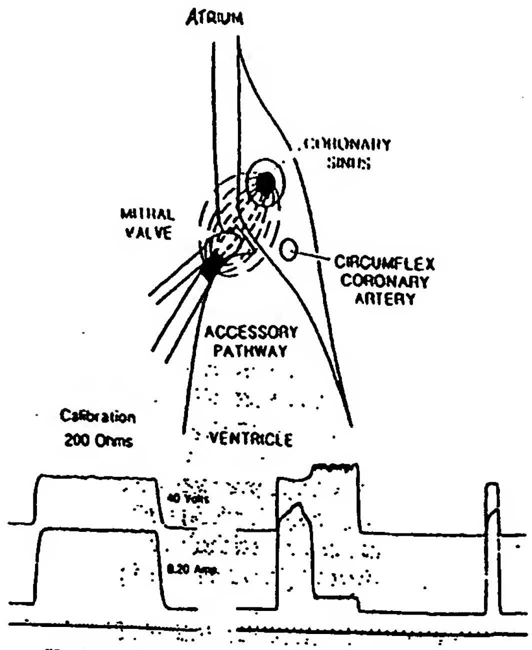


FIGURE 1. R.F. ABLATION OF ACCESSORY PATHWAY

Laser balloon angioplasty was introduced by J. Richard Spears, M.D.[3], in an attempt to reduce the restenosis rate associated with angioplasty. Heat is generated in the vessel walls by laser energy after inflation of an angioplasty balloon. Radio frequency is currently under study for T.B.A. because of its low cost as well as the possibility of utilizing the change in tissue impedance as a feedback control parameter. The R.F. balloon is made up of a set of Bi-Polar electrodes deposited on a standard angioplasty balloon. The R.F. current is passed through the tissue between the electrodes with the greatest current density located at the spacing between the electrodes on the balloon. During the application of the energy, the tissue will dehydrate raising the impedance of that tissue and altering the current path with heat in a dynamic way.

Recanalization with R.F. energy is shown in Figure 2. The object is to create maximum current density at the distal electrode plaque/thrombi location with minimum heat dissipated by both electrodes. The current passing through the tissue returns through the blood to the proximal electrode similar to that of the Bovie monopolar system. The area and conductance of the proximal electrode is chosen to minimize heating of the blood and/or tissue in contact with it. During the application of energy, the tissue at the distal electrode end will be heated by the associated high current density and with minimal force, the catheter can be advanced and the vessel recanalized. It can be seen that tissue heating is a function of current density and the electrical and thermal impedance.

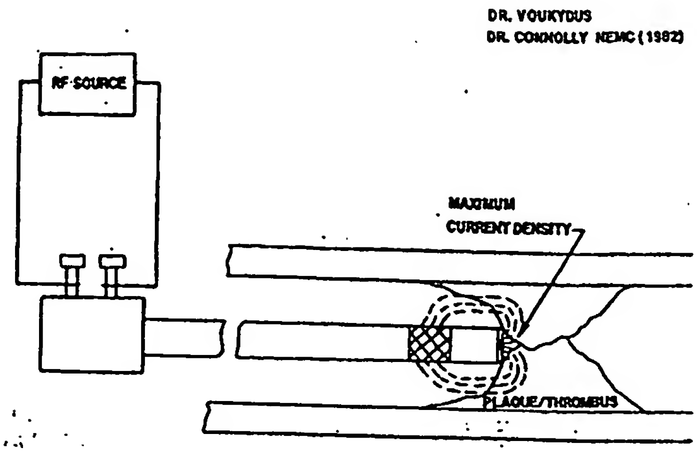
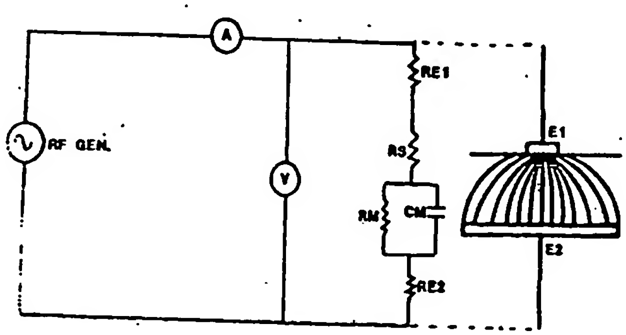


FIGURE 2. RF RECANALIZATION

A simple equivalent circuit (Figure 3) consists of an R.F. generator, a means for measuring current and voltage, electrode resistance (RE_1 and RE_2) in series with the tissue equivalent circuit (Cole[4]).

A pictorial, in Figure 3, is used to illustrate that the current density is a function of the applied current and indirectly of the electrode surface area in contact with the tissue. It illustrates that the current density is greatest at the surface interface of the smaller of the two electrodes (E_1). Furthermore, improved performance can be achieved by using highly conductive electrodes.



$P=I^2R$

FIGURE 3. EQUIVALENT CIRCUIT

R.F. voltage and current are measured and the impedance between the electrode is derived. This impedance is the tissue impedance between the electrode, and the changes in the impedance indicates what is happening during the applications of R.F. energy.

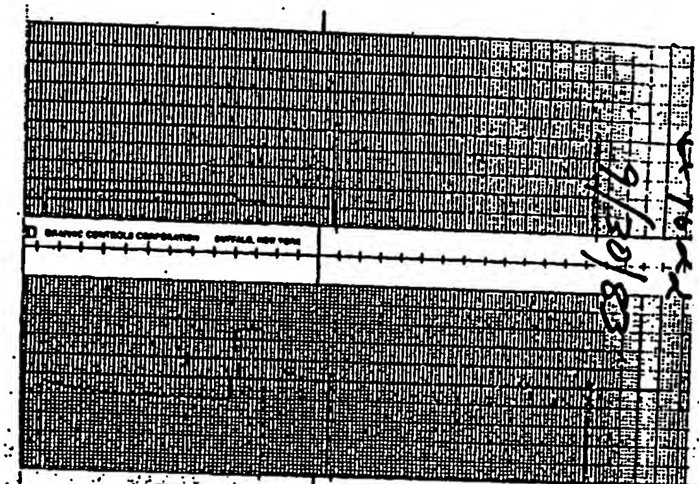


FIGURE 4 Cardiac Ablation

Figure 4 shows tracings of current (top) and impedance during an animal cardiac ablation (Zipes 1983). The impedance develops a negative slope with energy followed by an abrupt change in slope and amplitude.

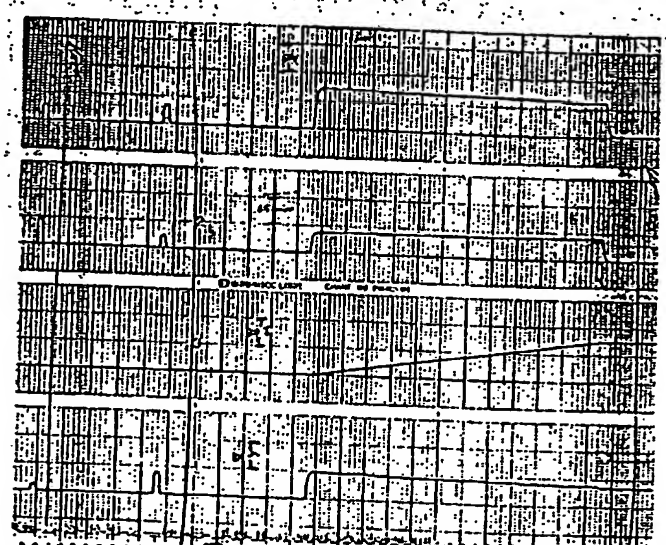
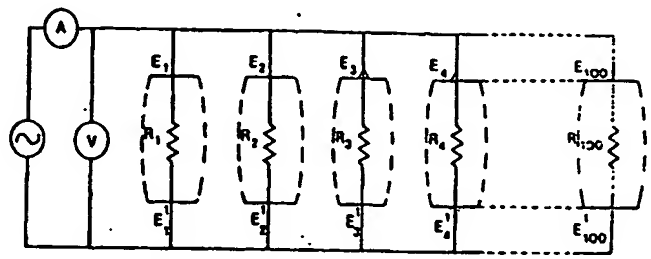


FIGURE 5. R.F.T.B.A.

Figure 5 is data from an animal R.F. T.B.A., the initial impedance slope is also negative but not as dramatic as in Figure 4.



R1 = R2 = R3 = R4 --- R100 = 10,000 Ω; REQ = 100 Ω

R1 = 6,000 Ω $\therefore$ REQ = 99 Ω, Δ 1 Ω

FIGURE 6. SIMPLIFIED LARGE ELECTRODE CIRCUIT

The equivalent circuit (Figure 6) illustrate the Bi-Polar electrodes of a R.F. T.B.A. balloon divided into 100 equal sets containing tissue impedance of 10K ohms each, resulting in a parallel resistance of 100 ohms. The change of 5K ohms in one set result in a change in the parallel resistance of 1 ohm.

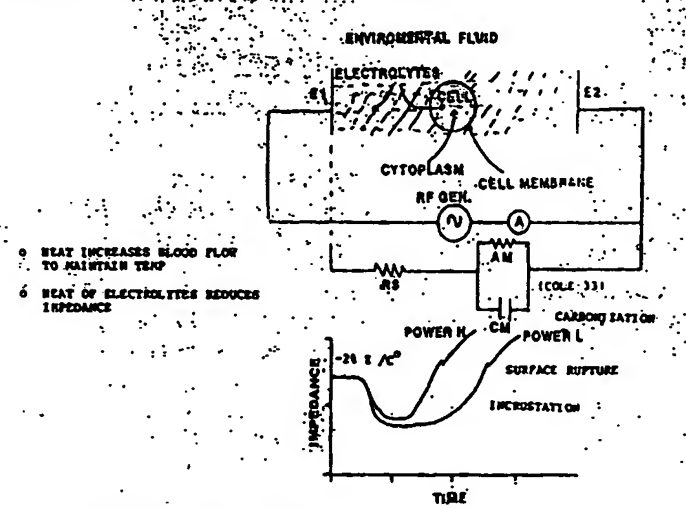


FIGURE 7. OBSERVED DATA

Figure 7 is an attempt to explain the observed data in terms of current density, heat, time and impedance. Figure 7a is a representation of the tissue between Bi-Polar electrodes consisting of electrolytes and cells. During the application of R.F. current through the tissue, heat is generated and causes an initial reduction in impedance (see Figure 7b) followed by a slope change, and a rapid rise in impedance. It was observed that during the rapid impedance rise, the tissue adjacent to the electrodes dehydrates, blanches and is followed by encrustation. The encrustation appears to trap the steam beneath the surface until the pressure causes rupturing. This is followed by reduction in impedance created by the new pathways. Continuation of the energy re-establishes the positive slope and leads to carbonization.

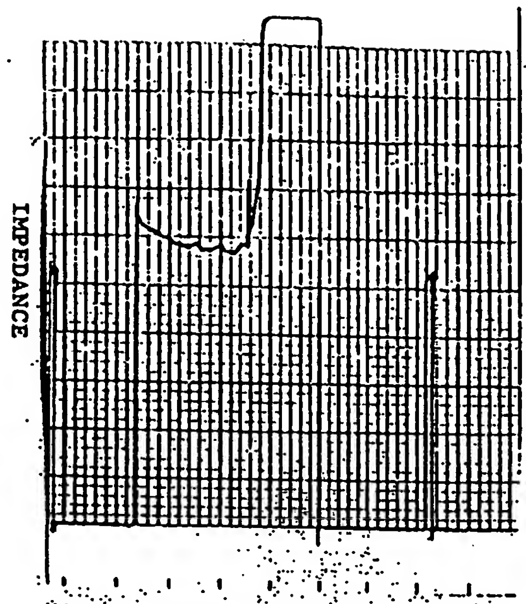


FIGURE 8. CARDIAC ABLATION DATA

Figure 8 illustrates the similarity to Figure 7 and the actual cadiac ablation data. This impedance information is used to limit the applied energy by establishing a slope and impedance cut-off point. The block diagram, Figure 9, shows a simple R.F. impedance feedback system utilizing a microprocessor based controller.

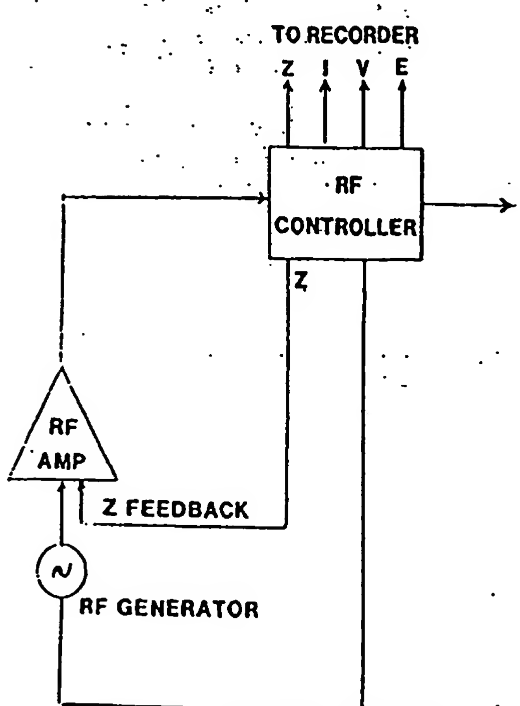


FIGURE 9. IMPEDANCE FEEDBACK

Summary:

Tissue impedance may allow the titration of energy during T.B.A., ablation and recanalization. Further studies need to be conducted to explain the impedance changes in normal and diseased human arteries.

Acknowledgments:

The author wishes to thank Alan West and John Abele of Boston Scientific Company for encouragement and review, and Raymond Connolly, PhD. of Tufts-New England Medical Center for his technical support.

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